Voluntary Conservation of Endangered Species: When Does "No Surprises" Mean No Conservation?

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ABSTRACT

Voluntary conservation agreements are becoming increasingly important in implementing the Endangered Species Act on private land. We analyze when such agreements arise and what level of conservation they generate in the presence of uncertainty about future government regulation and conservation benefits. Our results suggest that the likelihood of an agreement depends on the availability of assurances regarding future regulation. In particular, an agreement may not be reached if there is a high degree of uncertainty regarding future conservation requirements. The level of conservation attainable from an agreement depends on the likelihood of regulation, the bargaining power of the parties, the irreversibility of development, and the availability of assurances. Under conditions likely to hold in practice, a higher conservation level may be achieved by offering assurances. However, this level of conservation will not be optimal, and may be lower than that attainable from regulation.

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I. INTRODUCTION

The conservation of endangered species on private land has been a controversial subject for several years. The restrictions imposed on private activity by the Endangered Species Act (ESA) have raised vigorous opposition from property rights advocates. This has made these restrictions a politically sensitive subject, hindering enforcement of the ESA. On the other hand, protecting endangered species on private land may be instrumental in determining the overall success of recovery efforts under the ESA; more than half of the listed endangered species have at least 80% of their habitat on private land (FWS 1997).

It has been argued that the ESA has failed to attain its objective of protecting endangered species. A common argument is that it generates perverse incentives that might compel landowners to manage their land in a way that harms endangered species. This argument has been made by Polasky and Doremus (1998), Polasky (2001), and Innes (2000), and anecdotal evidence of such behavior abounds (see, e.g., Mann and Plummer 1995, Ruhl 1998, Bean 1998). Empirical evidence has been found in the case of the red-cockaded woodpecker (Michael and Lueck 2000).

Another argument made against the ESA is that it attempts to deter harmful conduct by landowners, but does nothing to encourage desirable behavior. In numerous cases the absence of harmful behavior may not be enough to address serious threats to endangered species. Many require active management of their habitat. These kinds of activities entail costs that even well-meaning landowners might not be willing to undertake. Additionally, there are opportunity costs of forgone revenue from the most profitable use of the property. Thus, the ESA seems to grant inadequate protection to endangered species on private land. Hence, there has been a call for the use of incentives to complement the existing regulatory framework.

At present the most widely used incentives programs are based on reforms to the ESA that provide landowners with assurances regarding future regulation. These reforms take the form of voluntary agreements, such as Habitat Conservation Plans (HCP) with a “no surprises” policy or Safe Harbor Agreements (SHAs) (Wilcove *et al.* 1996, Bean and Wilcove 1996, FWS 1999). A key characteristic of these programs is that the Fish and Wildlife Service (FWS) and a landowner reach a voluntary agreement on a conservation program to be implemented by the landowner. In return, FWS guarantees to the landowner that he will not have to incur additional costs or be subject to further restrictions in the future.

Given that voluntary incentives programs, in particular HCPs, have become the main vehicle for implementation of the ESA on private land (Defenders of Wildlife 1998, Thomas 2001), it is important to ask under what conditions a landowner and a regulator will agree on such a program, and what levels of conservation one might expect as an outcome. The use of incentives for conservation of endangered species has been examined by Smith and Shogren (2001,2002). Additionally, voluntary agreements have been analyzed in the context of pollution abatement (see, e.g. Arora and Cason 1995, Segerson and Miceli 1998, Wu and Babcock 1999), but these studies do not account for two issues that are particularly relevant in the context of endangered species conservation. The first one is the uncertainty inherent in the management of ecosystems and endangered species, which stems from our incomplete understanding of the biological world (Noss *et al.* 1997, Harding *et al.* 2001). The second, and closely related one, is the potential irreversibility of habitat loss and extinction as a result of land use decisions made as part of a voluntary agreement[1].

This paper builds on the framework provided by Segerson and Miceli (1998) to analyze the interaction between a regulator and a landowner. It expands on their study by incorporating uncertainty and irreversibility. The analysis shows that one of their main results, that a voluntary agreement is reached as long as there is a positive probability of regulation, does not hold under uncertainty. Specifically, we show that in the presence of uncertainty about future regulation and conservation benefits, the likelihood of an agreement depends on the availability of assurances regarding future regulation.

Our model also reveals that, under what is arguably the most common scenario in practice, HCPs and other incentives programs that provide assurances to landowners may result in higher conservation

[1] For general treatments of conservation under uncertainty and irreversibility see, for example, Arrow and Fisher (1974), Hanemann (1989), Usategui (1990), or Viscusi (1985, 1988).

levels than agreements that do not offer assurances. However, assurances-based agreements may yield inefficient levels of conservation, perhaps even lower than those attainable through regulation.

The remainder of the paper is organized as follows. Section II presents the basic setup of the model, section III analyzes the interaction of regulator and landowner when assurances are offered, while section IV does the same for the case of no assurances. Section V presents a numerical example, and section VI concludes.

II. MODEL SETUP

We analyze the interaction between a regulator and a landowner using a two-period model, in which the second period represents the entire future time horizon. Both the regulator and the landowner know the state of the world in period 1, ω_1, but do not know the state of the world in period 2, ω_2. This reflects the uncertainty inherent in managing endangered species. For instance, small populations may be severely affected by unpredictable changes in environmental factors such as weather or food supply, by natural catastrophes, or by stochastic demographic and genetic factors. Additionally, as new knowledge is gained about a species, further management needs may be identified, even if there are no significant changes in the species' environment. Therefore, management decisions made with the information available in period 1 may not be efficient *ex post*.

The sequence of events is as follows. In period 1 the regulator decides whether to offer a Voluntary Conservation Agreement (VCA) or not. A VCA specifies the conservation levels c_{v1} and c_{v2} for period 1 and 2, respectively. If the regulator decides to make the offer, the landowner must choose whether to accept it or not. If he accepts, then he agrees to conservation levels c_{v1} and c_{v2}. If the regulator decides not to make the offer, or the landowner does not accept it, then the landowner is regulated with probability p, and remains regulated in period 2[2]. If the landowner is not regulated he develops his entire property and no conservation takes place.

[2] Regulation is probabilistic because the regulator may be unable or unwilling to enforce the law due to information requirements, high burden of proof, or political considerations (Polasky and Doremus 1998).

Since the future state of the world is not known in period 1, it is possible that when new information becomes available the regulator will make further demands for conservation. A VCA also includes a provision that specifies whether such a “surprise” is allowed. We analyze how a “no surprises” provision would affect the likelihood that a VCA is reached, and the resulting levels of conservation in the two periods.

Let $B_t(c, \omega_t)$ be the benefits to society from conservation level c in period t, with corresponding state of the world ω. The argument ω_t in the benefit function will be omitted to simplify notation, and it is assumed that $B_t'(\cdot)>0$ and $B_t''(\cdot)< 0$, where the derivatives are with respect to c.

The cost of conservation is given by the compliance cost to the landowner[3] (including opportunity costs), $a_i(c)$, $i = v, m$. Following Segerson and Miceli (1998) we assume that both total and marginal costs are lower under a VCA than under regulation[4], and that costs of conservation are linear (i.e. $a_i(c)=a_i c$). The reasoning behind our assumption is similar to that of Segerson and Miceli. When a landowner agrees to a conservation plan voluntarily, he has more flexibility to decide how to implement it. For instance, he can choose which part of his property he prefers to set aside for conservation, or he can decide to purchase a different tract of land to implement the conservation plan. This cost advantage implies that $a_v < a_m$. The payoff to the regulator is given by net social benefits, which are $NSB_{it}(c_i)= B_t(c_i) - a_i c_i$. Note that the assumption about costs implies that $NSB_{vt}(c) > NSB_{mt}(c)$ for any c. The landowner incurs costs from conservation, but derives no benefits. All benefits and costs corresponding to period 2 are present values.

In the following sections we analyze the outcome of the interaction between the regulator and the landowner under two basic scenarios: when the regulator offers assurances to the landowner (no surprises), and when he does not (surprises). Additionally, for each scenario we examine how irreversibility affects the outcomes. Specifically, we define irreversibility by assuming that the

[3] For the sake of simplicity, we have left out the transaction costs to the regulator and assumed that the compliance costs are the same in both periods. These assumptions do not affect our results.
[4] Voluntary Conservation Agreements are assumed to be more cost-effective than command and control regulation. However, this may not be true for other forms of market-based regulation, such as tradable development rights.

conservation level in period 2 cannot exceed that from period 1: $c_{i2} \leq c_{i1}$. Intuitively, this implies that developed land cannot be converted back to wildlife habitat.

III. NO SURPRISES

A. NO IRREVERSIBILITY

In this section we assume that there is a "no surprises" clause in the agreement signed in period 1 by the regulator and the landowner. This means that the regulator guarantees that no additional conservation will be required in period 2, regardless of the new information that becomes available in the second period.

Given these assumptions, the landowner enters into a VCA if and only if

$$a_v c_{v1} + a_v c_{v2} \leq p[a_m c_{m1}^* + a_m E c_{m2}^*] \tag{1}$$

where c_{m1}^* and Ec_{m2}^* are the levels of conservation under regulation, set to maximize the expected net social benefit in each period. This implies that (c_{m1}^*, Ec_{m2}^*) is the only credible threat the regulator can make, since he would have an incentive to deviate from any other conservation levels. The regulator enters into a VCA if and only if

$$NSB_{v1}(c_{v1}) + E\, NSB_{v2}(c_{v2}) \geq p[NSB_{m1}(c_{m1}^*) + E\, NSB_{m2}(Ec_{m2}^*)] \tag{2}$$

Note that if we assume that there is no change in the state of the world, and therefore no uncertainty, and that $c_{i1} = c_{i2} = c_i$, conditions (1) and (2) can be rewritten as $2a_v c_v \leq 2pa_m c_m^*$ and $2NSB_v(c_v) \geq 2pNSB_m(c_m^*)$, respectively. These correspond to the case analyzed by Segerson and Miceli (1998). Thus, our model is a generalization of theirs, and this particular scenario is the one that corresponds most closely to their specification.

Condition (1) gives the set of all combinations of c_{v1} and c_{v2} that are acceptable to the landowner:

$$S_L = \{(c_{v1}, c_{v2}) |\, c_{v1} + c_{v2} \leq p\, \frac{a_m}{a_v} [c_{m1}^* + Ec_{m2}^*] \equiv \overline{C}\,\} \tag{3}$$

where $\overline{C}$ is the highest level of total conservation (for both periods) that the landowner will agree to. The set S_L is illustrated in Figure 1a.

Similarly, using condition (2) and the definition of net social benefits, we can define the set of all combinations of conservation levels acceptable to the regulator:

$$S_R = \{(c_{v1}, c_{v2}) | c_{v1} + c_{v2} \leq \frac{1}{a_v} [B_1(c_{v1}) + EB_2(c_{v2}) - p(NSB_m(c_{m1}^*) + ENSB_m(c_{m2}^*))]\} \quad (4)$$

Note that for small enough conservation levels the left hand side of (4) is positive, but the right hand side is negative, since the expected net social benefits from regulation are strictly positive. Thus, the inequality does not hold, which implies that there is a set of minimum conservation levels acceptable to the regulator. This set defines the lower boundary of S_R.

Likewise, for large enough levels of conservation the left hand side of (4) will be larger than the right hand side, since $B(\bullet)$ is concave. This means that there is also a set of maximum total conservation levels acceptable to the regulator. This set defines the upper boundary of S_R.

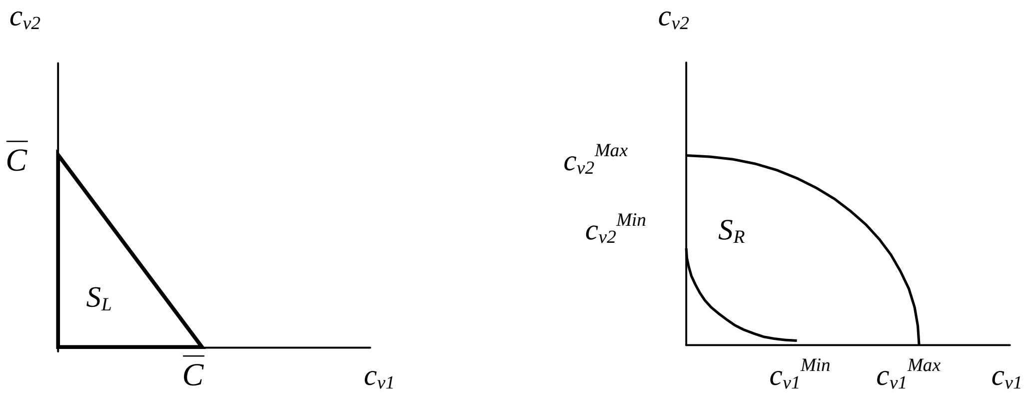
The shape of the boundaries of S_R can be described by using the second-order derivative of $c_{v2}(c_{v1})$:

$$\frac{d^2 c_{v2}(c_{v1})}{dc_{v1}^2} = -\frac{\dfrac{d^2 NSB_{v1}(c_{v1})}{dc_{v1}^2} + \dfrac{d^2 NSB_{v2}(c_{v2})}{dc_{v2}^2}\left(\dfrac{dc_{v2}}{dc_{v1}}\right)^2}{\dfrac{dNSB_{v2}(c_{v2})}{dc_{v2}}}$$

Given $dNSB_{v2}(c_{v2})/dc_{v2} > 0$ and $dNSB_{v2}(c_{v2}^1)/dc_{v2}^1 < 0$ for the lower and upper boundaries, respectively, and the concavity of $NSB_v(\bullet)$, we have $d^2c_{v2}/dc_{v1}^2 > 0$ for the lower boundary and $d^2c_{v2}/dc_{v1}^2 < 0$ for the upper boundary. The set S_R is illustrated in Figure 1b.

FIGURE 1

Sets of acceptable conservation levels

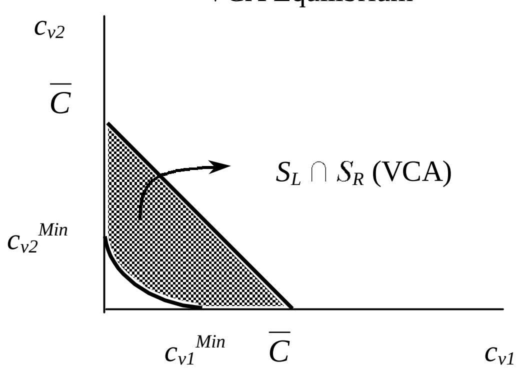


(a) Landowner *(b) Regulator*

A VCA is possible whenever there is an intersection between S_L and S_R. This may be the case, for instance, if c_{v1}^{Min} or c_{v2}^{Min} (or both) are smaller than $\overline{C}$, where c_{v1}^{Min}, c_{v2}^{Min} are defined by $c_{v2}(c_{v1}^{Min}) = 0$ and $c_{v2}(0) = c_{v2}^{Min}$. This is shown in Figure 2 (henceforth, the upper boundary of S_R is not drawn to avoid cluttering the graph).

FIGURE 2

VCA Equilibrium



Note that if $p = 0$, the regulator will agree to any positive level of conservation, but the landowner will not accept any level of conservation. Thus, $p > 0$ is a necessary condition for a VCA. As proved in the Appendix, $c_{v1}^{Min} \leq \overline{C}$ and $c_{v2}^{Min} \leq \overline{C}$ for any positive probability of regulation. Therefore, $p > 0$ is also a sufficient condition for a VCA. This establishes the following proposition (which is analogous to Proposition 1 in Segerson and Miceli 1998).

PROPOSITION 1. *If assurances are offered as part of a VCA and the actions taken in period 1 are reversible, a VCA will be the equilibrium outcome of the interaction between landowner and regulator for any $p > 0$.*

The proof of Proposition 1, as well as all subsequent propositions, can be found in the Appendix.

As in Segerson and Miceli (1998), the result in Proposition 1 can be explained by the cost advantage offered by VCAs, which makes it in the best interest of both parties to enter into such an agreement. As section IV will show, however, the existence of assurances plays a key role in generating the result.

Equilibrium Outcomes

Up to now, we have shown that a VCA is possible for any p > 0, and any (c_{v1}, c_{v2}) combination in $\{S_L \cap S_R\}$ could be an equilibrium outcome. In this section, we turn our attention to the actual level of conservation resulting from a VCA. To establish a basis for comparison, let us define the first-best conservation levels. To obtain the first-best outcome, the regulator would maximize net social benefits in period 1, then observe the state of the world in period 2 and maximize the net social benefits in that period. Let c_{v1}^F and c_{v2}^F be the first-best conservation levels in period 1 and 2, respectively. To illustrate, suppose that the benefit function is given by $B_t(c_{it}, \omega_t) = A(c_{it}+\omega_t) - (c_{it}+\omega_t)^2/2$, where $\omega_t > 0$, $i = v, m$, $t = 1, 2$. Then the regulator chooses c_{vt} to maximize $NSB_{vt}(c_{vt}, \omega_t)=A(c_{vt}+\omega_t) - (c_{vt}+\omega_t)^2/2 - a_v c_{vt}$ in period $t = 1, 2$. The resulting first-best conservation levels are $c_{v1}^F = A - \omega_1 - a_v$ and $c_{v2}^F = A - \omega_2 - a_v$. Under this scenario, the regulator can choose the period 2 conservation level after ω_2 is observed.

This first-best outcome may not be reached in a no-surprises VCA, since c_{v2} must be determined in the first period, when ω_2 is unknown. That is, a no-surprises VCA can at most achieve a second-best outcome by choosing c_{v1} and c_{v2} in period 1 to maximize the expected net social benefits over the two periods:

$$NSB_{v1}(c_{v1,}\omega_1)+E\ NSB_{v2}(c_{v2,}\omega_2) = A(c_{v1}+\omega_1) - (c_{v1}+\omega_1)^2/2 \ - a_v c_{v1} \ + A(c_{v2}+E\omega_2) - (c_{v1}+E\omega_2)^2/2 \ - a_v c_{v2} \tag{5}$$

The resulting second-best conservation levels are

$$c_{v1}^* = A - \omega_1 - a_v \text{ and } c_{v2}^* = A - E\omega_2 - a_v \tag{6}$$

where $E\omega_2 > 0$. Note that $c_{v1}^F = c_{v1}^*$, since the state of the world in period 1 is known.

The actual level of conservation resulting from a VCA could be any combination in $\{S_L \cap S_R\}$, depending on the degree of bargaining power of the regulator and the landowner[5]. In what follows, we consider two extreme cases.

(a) *Type I Equilibrium.* Suppose first that the regulator has all of the bargaining power, in the sense that he can choose the conservation levels that maximize the expected net social benefits from conservation, subject to a participation constraint for the landowner:

$$\max_{c_{v1},\, c_{v2}} \quad NSB_{v1}(c_{v1,}\omega_1) + E\ NSB_{v2}(c_{v2,}\omega_2) \qquad \text{subject to} \quad c_{v1} + c_{v2} \leq \overline{C} \tag{7}$$

Solving this problem yields the following results, which are proved in the Appendix.

PROPOSITION 2: *(i) Under a VCA with a no-surprises clause, the first-best conservation level will generally not be achieved if future conservation benefits are uncertain. (ii) When the regulator has the bargaining power, the second-best conservation level will be achievable only if $p(a_m/a_v) > 1$. If $p(a_m/a_v) < 1$, the total level of conservation under a voluntary agreement will be lower than that attainable under regulation.*

Proposition 2 suggests that the second-best outcome is possible only if the background threat of regulation is highly credible and the cost advantage of voluntary programs is large. Otherwise, the conservation level under a VCA is lower than that achievable under regulation.

[5] "Bargaining power" in this context is defined as the ability to make a take-it-or leave-it offer. That is, the party that has the bargaining power can be thought of as moving first and offering a conservation level to the other party.

(b) *Type II Equilibrium.* Suppose now that the landowner has all of the bargaining power, in the sense that he chooses the conservation levels that minimize his expected costs, subject to a participation constraint for the regulator:

$$\min_{c_{v1},\, c_{v2}} \quad a_v c_{v1} + a_v c_{v2} \qquad \text{subject to} \quad (c_{v1}, c_{v2}) \in S_R \tag{8}$$

Clearly, the landowner will choose conservation levels on the lower boundary of S_R[6]. This implies that the resulting total conservation level cannot be higher than the total conservation level achieved when the regulator has the bargaining power. Additionally, the total conservation level is smaller than the expected total conservation level under regulation if the background threat of regulation is highly credible and the cost advantage of voluntary agreements is large. Specifically, we obtain the following results (see the appendix for a proof).

PROPOSITION 3: *If the landowner has the bargaining power, the total two-period conservation level achieved under a VCA will be no larger than that attained when the regulator has the bargaining power. Furthermore, if $p(a_m/a_v) < 1$, the total conservation level under a VCA will be lower than that attainable under regulation.*

The results in Propositions 2 and 3 suggest that the parties' bargaining power can have a significant effect on the outcome of a voluntary conservation agreement. Most agreements of this type are initiated by landowners (Defenders of Wildlife 1998), i.e. they have the bargaining power. Furthermore, enforcing the ESA may be quite difficult in practice due to information requirements, high burden of proof, and possibly political considerations (Polasky and Doremus 1998). This amounts to saying that p has traditionally been relatively low. Thus, even in cases when the regulator has the bargaining power, the outcome may be lower than the second-best. This implies that the conservation levels achieved by VCAs are likely to be inadequate, often below what would be achieved under regulation.

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[6] Specifically, the landowner will choose the point on the lower boundary of S_R that is tangent to an isocost line.

B. IRREVERSIBILITY

We now assume that the conservation level in period 2 can be no larger than that in period 1. This would be the case if, for example, the landowner is allowed to develop part of his forest in period 1 (e.g. build a house) as part of the VCA.

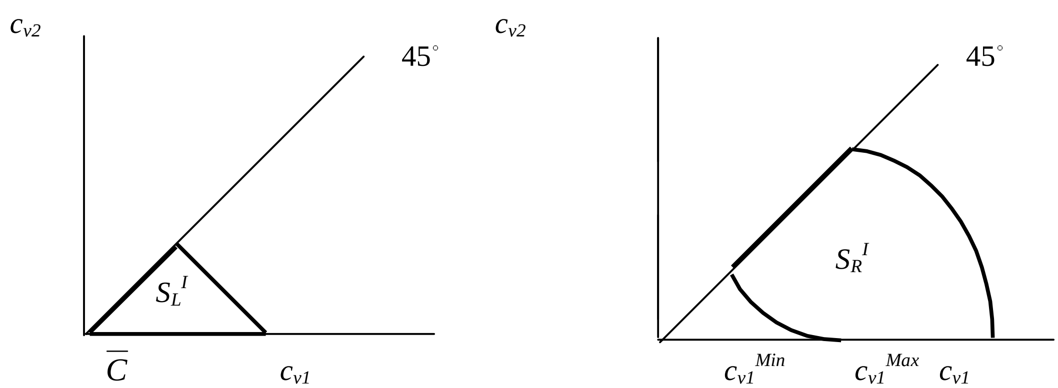
The set of acceptable conservation levels for the landowner and the regulator under irreversibility are given by

$$S_L^I = \{(c_{v1}, c_{v2})|\ c_{v1} + c_{v2} \leq \overline{C}\ , c_{v2} \leq c_{v1}\} \tag{9}$$

$$S_R^I = \{(c_{v1}, c_{v2})|c_{v1} + c_{v2} \leq \overline{C} + \frac{1}{a_v}[B_1(c_{v1}) + EB_2(c_{v2}) - p(B_1(c_{m1}^*) + E\,B_2(c_{m2}^*))], c_{v2} \leq c_{v1}\} \tag{10}$$

Note that $S_L^I \subset S_L$ and $S_R^I \subset S_R$. This has the effect of decreasing the number of combinations of c_{v1} and c_{v2} acceptable to the landowner and the regulator. The sets S_L^I and S_R^I are depicted in Figures 3a and 3b, respectively.

FIGURE 3
Set of acceptable conservation levels under irreversibility



(a) Landowner *(b) Regulator*

As in the preceding section, a VCA will be the equilibrium outcome of the interaction between the landowner and the regulator for any positive probability of regulation, since $c_{v1}^{Min} \leq \overline{C}$ implies that $S_L^I \cap S_R^I \neq \emptyset$ (this follows from the proof of Proposition 1). Thus, irreversibility does not affect the result that a VCA is reachable for any $p > 0$. However, it may affect the resulting equilibrium conservation levels. Specifically, the fact that $\{S_L^I \cap S_R^I\} \subset \{S_L \cap S_R\}$ implies that some conservation levels attainable under our original assumption are no longer feasible under irreversibility. In particular, the second-best conservation levels (c_{v1}^*, c_{v2}^*) may no longer be attainable, even if they are acceptable to the landowner.

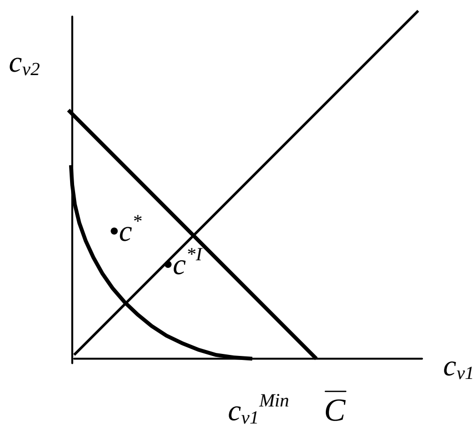
To illustrate this point, consider the example used in the preceding section. In a Type I equilibrium the regulator would choose conservation levels for both periods to solve

$$\max_{c_{v1},c_{v2}} \quad A(c_{v1}+\omega_1) - (c_{v1}+\omega_1)^2/2 - a_v c_{v1} + A(c_{v2}+E\omega_2) - (c_{v2}+E\omega_2)^2/2 - a_v c_{v2}$$

$$\text{subject to} \qquad c_{v1} + c_{v2} \leq \overline{C}\,;\; c_{v2} \leq c_{v1} \tag{11}$$

Suppose that the participation constraint is not binding, but that the irreversibility constraint is. Then the regulator would choose $c_{v1}^{*I} = c_{v2}^{*I} = A - (\omega_1 + E\omega_2)/2 - a_v$ (i.e. point c^{*I} in Figure 4), which differ from c_{v1}^* and c_{v2}^*, the second-best conservation levels (i.e. point c^* in Figure 4).

FIGURE 4
VCA Equilibrium Under Irreversibility



If the participation constraint is binding as well, the regulator will choose conservation levels $\overline{C}/2$ in both periods. Finally, in a Type II equilibrium the landowner minimizes $a_v c_{v1} + a_v c_{v2}$ subject to $(c_{v1}, c_{v2}) \in S_R^I$ and $c_{v2} \leq c_{v1}$. Thus, his choice of conservation levels will be on the lower boundary of the set $\{S_L^I \cap S_R^I\}$.

In sum, by limiting the set of feasible outcomes, irreversibility further curtails the regulator's ability to obtain desirable conservation results under a VCA. There are many examples where irreversibility plays an important role. For instance, a number of HCPs in the southeastern United States are limited to translocating red-cockaded woodpeckers from private to federal forests, in order to harvest the former. However, critics of these plans contend that male woodpeckers do not adapt easily to their new surroundings, and often attempt to return to their original home (Kaiser, 1997). Of course, once their original habitat has been harvested, there is little else that can be done to correct the problem. This provides an argument for the regulator to exercise caution regarding the conditions he agrees to under a VCA.

IV. SURPRISES

In this section we consider a setting in which "surprises" are possible, in the sense that in period 2 the regulator may impose conservation requirements on the landowner which go beyond those agreed to in period 1. To illustrate the difference between the surprises and no-surprises scenarios, consider the case of one of the safe-harbor programs for red-cockaded woodpeckers in North Carolina (Defenders of Wildlife 1998). Under this program, participating landowners agreed to perform voluntary habitat management for woodpeckers that already occupied their property and to enhance habitat in other parts of the land not inhabited by the birds. Under a surprises scenario, further land-use restrictions would be imposed if additional woodpeckers occupied the newly enhanced habitat. However, given the assurances provided by the agreement under the no-surprises policy, any additional woodpecker settlements on the property will not trigger further restrictions.

A. NO IRREVERSIBILITY

In this section, we assume that the regulator and landowner agree on conservation levels c_{v1} and c_{v2} in period 1, but the regulator does not offer any assurances regarding additional conservation in period 2. Specifically, with probability q, $0 < q \leq 1$, the regulator will surprise the landowner by requiring additional conservation c_s in period 2[7], where $ENSB_{v2}(c_{v2} + c_s) > E\ NSB_{v2}(c_{v2})$. The amount of additional conservation required depends on ω_2, the state of the world in period 2, which makes c_s a stochastic

[7] We assume that the probability q is exogenous. It may be interpreted as the likelihood that ω_2 reaches some threshold that triggers additional conservation, or it may characterize the regulator's *a priori* unknown willingness or ability to require more conservation.

variable[8]. For simplicity, we assume that it is normally distributed: $c_s \sim N(c_s^E, \sigma^2)$, which implies that $(c_s - c_s^E)/\sigma \sim N(0,1)$. Thus,

$$q = Pr[c_s > 0] = Pr[(c_s - c_s^E)/\sigma > -c_s^E/\sigma] = 1 - Pr[(c_s - c_s^E)/\sigma \leq -c_s^E/\sigma] = 1 - \Phi(\gamma),$$

where $\gamma \equiv -c_s^E/\sigma^2$ and $\Phi(\bullet)$ is the cumulative density function for the standard normal distribution. The truncated mean of c_s is given by (Greene 2000)

$$E(c_s|c_s > 0) = c_s^E + \frac{\sigma\phi(\gamma)}{q} \tag{12}$$

where $\phi(\bullet)$ is the probability density function for the standard normal distribution.

Under these conditions, the landowner will enter into a VCA if and only if

$$a_v c_{v1} + a_v c_{v2} + q a_v c_s^E + \sigma\phi(\gamma) \leq p a_m (c_{m1}^* + E c_{m2}^*)$$

Thus, the acceptance set for the landowner is

$$S_L' = \{(c_{v1}, c_{v2}) | c_{v1} + c_{v2} \leq \overline{C} - q c_s^E - \sigma\phi(\gamma) = \overline{C} - qE(c_s|c_s > 0) \equiv \overline{C'}\} \tag{13}$$

where $\overline{C'}$ gives the maximum level of conservation acceptable to the landowner when no assurances are offered. Note that $\overline{C'} < \overline{C}$, and that the difference is affected by the amount of the expected surprise and by the degree of uncertainty, as measured by the standard deviation σ. This implies that $S_L' \subset S_L$. That is, the possibility of a surprise in period 2 reduces the likelihood that the landowner will be willing to enter into a VCA. The reason is clear: a possible surprise means potentially larger costs for the landowner, so he has less to gain from entering into an agreement.

The regulator will enter into a VCA if and only if

$$NSB_{v1}(c_{v1}) + qENSB_{v2}(c_{v2} + c_s^E + \sigma\phi(\gamma)/q) + (1-q)ENSB_{v2}(c_{v2}) \geq p[NSB_{m1}(c_{m1}^*) + E\, NSB_{m2}(c_{m2}^*)]$$

Thus, the acceptance set for the regulator is

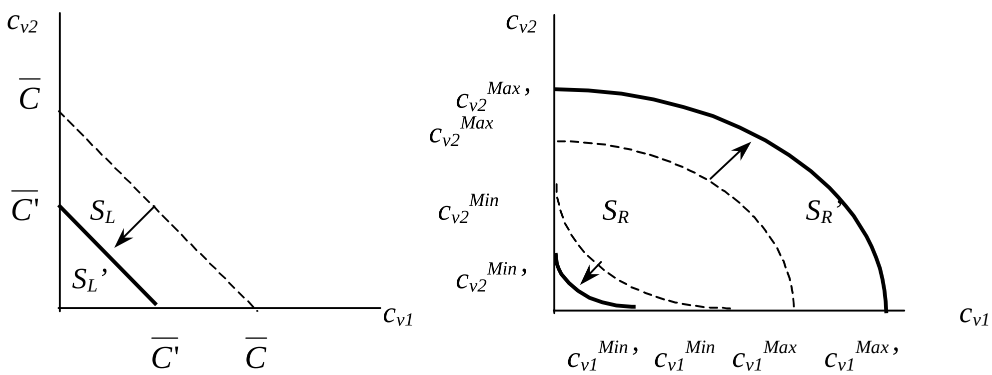
[8] In order to focus on the effect of surprises on first period decisions, we assume that the landowner will comply with the regulator's demand for more conservation in period 2. The underlying supposition is that, should the landowner refuse to comply, he will be regulated with probability one in the second period, and that the resulting costs (possibly including fines) would be high enough to deter him from not complying. This can be justified by noting that, by participating in period 1, the landowner reveals private information about his land to the regulator, thereby assuring that he will be regulated in period 2 if he does not comply.

$$S_R{}' = \{(c_{v1}, c_{v2}) | c_{v1} + c_{v2} \leq \overline{C} + \frac{1}{a_v}[B_1(c_{v1}) + EB_2(c_{v2}) - p(B_1(c_{m1}{}^*) + E\, B_2(c_{m2}{}^*))]$$

$$+ \frac{1}{a_v} q[E\, B_2(c_{v2} + c_s{}^E + \sigma\phi(\gamma)/q) - E\, B_2(c_{v2}) - a_v(c_s{}^E + \sigma\phi(\gamma)/q)]\} \qquad (14)$$

Note that the last term in brackets on the right-hand side of (14) is $E\ NSB_{v2}(c_{v2} + Ec_s) - E\ NSB_{v2}(c_{v2}) > 0$. This implies that the regulator is more likely to enter into a VCA than under the no-surprises scenario. The reason is that, by not offering assurances, the regulator retains the flexibility to use the information that becomes available in the second period and thereby increase net social benefits. Figure 5 shows the changes in the sets of acceptable conservation levels when going from a no-surprises to a surprises scenario.

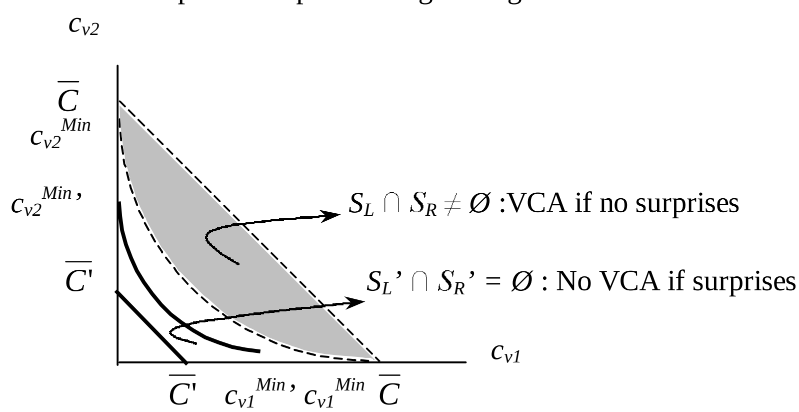
FIGURE 5
Changes in sets of acceptable conservation levels



(a) Landowner *(b) Regulator*

Since the landowner is less willing to enter into a VCA when surprises are possible, and the regulator is more willing to enter, the net effect of surprises on the likelihood of reaching a VCA is ambiguous. However, a potential surprise raises the possibility that no VCA will be reached. That is, proposition 1 does not hold when assurances are not offered. Specifically, if the expected surprise and the degree of uncertainty are large enough, the landowner's set of acceptable conservation levels can shrink more than the regulator's set expands, so that there is no intersection between these sets. This possibility is shown in Figure 6, where the dashed lines represent the no-surprises scenario and the solid lines represent the surprises scenario.

FIGURE 6
No VCA if the expected surprise is large enough



No VCA will be reached in the surprises scenario if $c_{v2}'(c_{v1}) > \overline{C'} - c_{v1}$ for any $c_{v1} \in [0, \overline{C'}]$. This may be the case if the expected additional conservation and the degree of uncertainty are large. Specifically, for the quadratic benefit function we can show that $c_{v2}'(c_{v1}) > \overline{C'} - c_{v1}$ for any $c_{v1} \in [0, \overline{C'}]$ if

$$c_s^E + \frac{\sigma\phi(\gamma)}{q} > \left[\frac{2(Dc_{v1} - c_{v1}^2) + E}{q(1-q)}\right]^{\frac{1}{2}} \quad \forall\, c_{v1} \in [0, \overline{C'}] \tag{15}$$

where D and E are functions of the parameters (see the Appendix). In Section V, we give an example of parameter values for which this condition holds. This result is summarized in the following proposition.

PROPOSITION 4: *If no assurances are offered, the regulator and the landowner will not reach a VCA if $c_{v2}'(c_{v1}) > \overline{C'} - c_{v1}$ for any $c_{v1} \in [0, \overline{C'}]$. This may be the case if the expected surprise and the degree of uncertainty are large.*

Proposition 4 shows that when surprises are possible the regulator and the landowner may not be able to reach an agreement, whereas they will always do so in a no-surprises scenario. These results suggest that offering assurances to landowners may increase the likelihood that they will enter into a VCA, particularly in cases where there is significant uncertainty about future conservation needs.

The actual experience with HCPs seems to confirm this intuition. Although HCPs were incorporated into the ESA in 1982, less than 50 plans had been requested and approved before the "no surprises" policy was announced in 1994. In 1995 this number shot up to close to 130 plans (Kaiser 1997). As of February of 2001, 341 HCPs covering 30 million acres had been approved (FWS 2001).

Equilibrium Outcomes

As in the no-surprises scenario, we consider two types of equilibrium, based on which party has the bargaining power.

Type I Equilibrium

In a Type I equilibrium the regulator has the bargaining power. If additional conservation is required in the second period, he will set c_s so that $c_{v2} + c_s = c_{v2}^F$. Therefore, in period 1 he chooses conservation levels c_{v1} and c_{v2} to maximize

$$NSB_{v1}(c_{v1}) + q\ ENSB_{v2}(Ec_{v2}^F) + (1-q)\ ENSB_{v2}(c_{v2})$$

subject to $$c_{v1} + q\ Ec_{v2}^F + (1-q)c_{v2} \leq \overline{C} \qquad (16)$$

where Ec_{v2}^F is the expected value of c_{v2}^F in period 1. In this case, we can prove the following results.

PROPOSITION 5: *(i) If the regulator has the bargaining power in a VCA that does not offer assurances, the first-best outcome is achievable if $p(a_m/a_v) > 1$. Under these conditions, a surprises VCA will generate at least as much conservation as a no-surprises VCA. (ii) If $p(a_m/a_v) \leq 1$, the first-best outcome is generally not achieved. Furthermore, the resulting conservation level may be lower than in a no-surprises VCA, and lower than that attainable under regulation.*

The proof of proposition 5 is given in the appendix. The results in proposition 5 suggest that a surprises VCA will be preferred to a no-surprises VCA as long as the threat of regulation and the cost advantage of voluntary agreements are high enough. However, if the threat of regulation and the cost advantage are not high enough, a no-surprises VCA may result in a higher level of conservation.

Type II Equilibrium

In a Type II equilibrium the landowner has the bargaining power. In period 1 he chooses conservation levels c_{v1} and c_{v2} to minimize

$$a_v c_{v1} + q\, a_v(Ec_{v2}^F) + (1-q) a_v c_{v2}$$

subject to $\quad (c_{v1}, c_{v2}) \in S_R' \quad$ (17)

In this case, we can prove the following results (see the proof in the appendix).

PROPOSITION 6: *(i) If the landowner has the bargaining power in a VCA that does not offer assurances, the first-best outcome will generally not be reached. (ii) If no additional conservation takes place in the second period, the total conservation level may be lower than when the regulator has the bargaining power. Furthermore, if $p(a_m/a_v) \leq 1$, the total conservation is lower than in a no -surprises VCA and lower than that attainable under regulation.*

The results presented in Propositions 4, 5, and 6 suggest that landowners who face uncertain and potentially significant costs from additional conservation requirements may not be willing to commit to high conservation levels, and may even be unwilling to participate in an agreement at all. This highlights the role that assurances can play as an incentive for landowners to participate in conservation programs. On the other hand, offering assurances limits the regulator's ability to incorporate new information into his management choices and may thereby preclude him from achieving desirable outcomes.

This tradeoff motivates a comparison of the conservation outcomes under the surprises and no-surprises scenarios. A key distinction is that, if the regulator has the bargaining power, a VCA that allows for surprises can achieve the first-best total conservation level, whereas a no-surprises agreement may not. A more interesting comparison is with the case where no additional conservation takes place (i.e. $c_s = 0$), because the outcome depends only on choices made in the first period, as in a no-surprises VCA.

When regulation is likely and the regulator has the bargaining power, a VCA that allows for surprises will bring about at least as much conservation as a no-surprises VCA. However, if these conditions do not hold, a no-surprises VCA may well yield a higher conservation level. There are two main effects behind these results. A large and highly uncertain surprise decreases the conservation levels that the landowner is willing to accept. On the other hand, it makes the regulator more willing to accept low conservation levels. As a result, if no additional conservation takes place the resulting conservation level will be low.

The most common scenario in practice is likely to be characterized by a low probability of regulation and the landowner possessing bargaining power. Hence, these results suggest that the FWS's current approach of offering no-surprises agreements to landowners may be somewhat justified. However, the resulting conservation levels, as argued, are likely to be inefficient.

B. IRREVERSIBILITY

If we relax the assumption that the actions from period 1 are reversible, the acceptance sets for the landowner and the regulator are the same as in conditions (13) and (14), with the addition of the constraint $c_{v2} + c_s \leq c_{v1}$. The analysis for this case is analogous to the corresponding case in the no-surprises scenario, so we do not repeat it. The results are equivalent as well: although a VCA may be reachable under irreversibility, the equilibrium outcomes may be different than under reversibility. In particular, the first-best outcome can be achieved only if $c_{v2}^F \leq c_{v1}^F$.

The Case for a Combination of Incentives

Let us focus on what is probably the most common outcome from a VCA. Suppose that the landowner has the bargaining power, that the probability of regulation is low, and that a no-surprises VCA has been reached. Recall that, in such a situation, the resulting total level of conservation would be lower than the first best and possibly lower than that attainable under regulation as well. A relevant policy question, then, is how to increase the conservation level offered by the landowner. As we will show, offering a side payment to the landowner for entering into a VCA can increase the conservation level he offers.

The landowner chooses to offer (c_{v1}^L, c_{v2}^L) to enter into a VCA by minimizing his costs subject to a participation constraint for the regulator (see (8)). Suppose that the regulator offers to the landowner a side payment of $S(c_{v1},c_{v2})$ for conservation levels c_{v1} and c_{v2} in the two periods. Then the landowner solves

$$\max_{c_{v1},\, c_{v2}} \quad -a_v c_{v1} - a_v c_{v2} + S(c_{v1}, c_{v2})$$

$$\text{subject to} \qquad (c_{v1}, c_{v2}) \in S_R \tag{18}$$

It is easy to see that the landowner will offer a conservation level higher than the minimum whenever the side payment is higher than the expected cost difference, i.e. $S(c_{v1},c_{v2}) > a_v[(c_{v1}+c_{v2}) - (c_{v1}^L+c_{v2}^L)]$. Furthermore, if the side payment is set equal to the expected net social benefits from conservation, i.e. $S(c_{v1},c_{v2}) = B_1(c_{v1}) + E\, B_2(c_{v2})$, then (18) has the same objective as the regulator's expected benefit maximization problem (7). Thus the landowner will offer c_v^*, which is the same conservation level the regulator would offer.

This result suggests that the conservation outcomes from VCAs can be improved by offering financial incentives to landowners in addition to assurances. These could take the form of cost-sharing payments for the management activities necessary to generate c_v, or "rent" payments that compensate for income lost because of carrying out those activities.

V. NUMERICAL EXAMPLE

In this section, we present a numerical example to illustrate the main points made in this paper. We assume that the benefit function is quadratic: $B_t(c_{it})=A(c_{it}+\omega_t) - (c_{it}+\omega_t)^2/2$, where A, $\omega_t > 0$.

a. No Surprises

We begin with the case where the VCA offers assurances. The parameters values are: $A = 1800$, $\omega_1 = 8$, $E\omega_2 = 7$, $a_m = 1.1$, $a_v = 0.6$. Table I shows the conservation outcomes for various levels of p and different allocations of bargaining power (BP=R for regulator, L for landowner).

TABLE I

No-Surprises Conservation Outcomes

Scenario	$\overline{C}$	(c_{v1}^*, c_{v2}^*)	(c_{v1}^R, c_{v2}^R)	$(c_{v1}^{RI}, c_{v2}^{RI})$	(c_{m1}^*, Ec_{m2}^*)	(c_{v1}^L, c_{v2}^L)
1a: p=0.8, BP=R	5255	**(1791,1792)**+	-------	-------	(1791,1792)	-------
2a: p=0.4, BP=R	2627	(1791,1792)	**(1313,1314)**+	-------	(1791,1792)	-------
3a: Irreversibility p=0.8, BP=R	5255	(1791,1792)	-------	**(1791,1791)**+	(1791,1792)	-------
4a: p=0.8, BP=L	5255	-------	--------	-------	(1791,1792)	**(986,987)**+

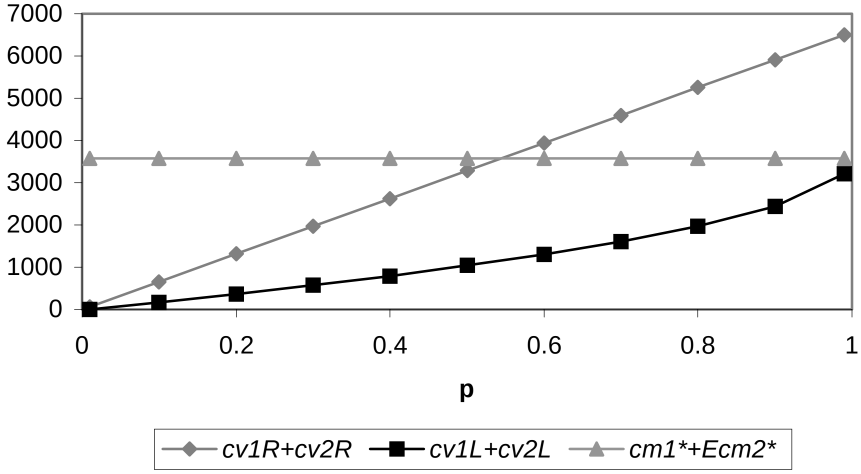
The final outcome in each scenario is indicated by the + sign.

Scenarios 1a and 2a illustrate the effect of lowering the probability of regulation. The second best outcome, (c_{v1}^*, c_{v2}^*), is lower than the maximum acceptable to the landowner: $c_{v1}^* + c_{v2}^* = 3583 < \overline{C} = 5255$. Thus the outcome in Scenario 1a is (c_{v1}^*, c_{v2}^*). In Scenario 2a, the probability of regulation is lower, and hence so is $\overline{C}$. The second best outcome (c_{v1}^*, c_{v2}^*) is now higher than $\overline{C}$, so it is not acceptable to the landowner. Thus, the outcome is (c_{v1}^R, c_{v2}^R), where $c_{v1}^R + c_{v2}^R = 2627$, which is lower than that attainable under regulation.

Scenario 3a illustrates the effect of irreversibility. Since $c_{v2}^* > c_{v1}^*$, this outcome is not feasible under irreversibility. Hence, the regulator chooses $(c_{v1}^{RI}, c_{v2}^{RI}) = (1791,1791)$, which is lower than the level of conservation attained when there is no irreversibility.

Finally, Scenario 4a shows the outcome when the landowner has the bargaining power. He chooses conservation levels (c_{v1}^L, c_{v2}^L). Note that the total conservation level is lower than that obtained when the regulator has the bargaining power. It is also lower than that attainable under regulation. This can be seen in Figure 7, which shows the outcomes for different levels of p when the regulator has the bargaining power $(c_{v1}^R + c_{v2}^R)$, the landowner has the bargaining power $(c_{v1}^L + c_{v2}^L)$, and under regulation $(c_{m1}^* + Ec_{m2}^*)$. Note that $c_{v1}^L + c_{v2}^L < c_{v1}^R + c_{v2}^R = \overline{C}$, so that a VCA is an equilibrium, for all $p > 0$.

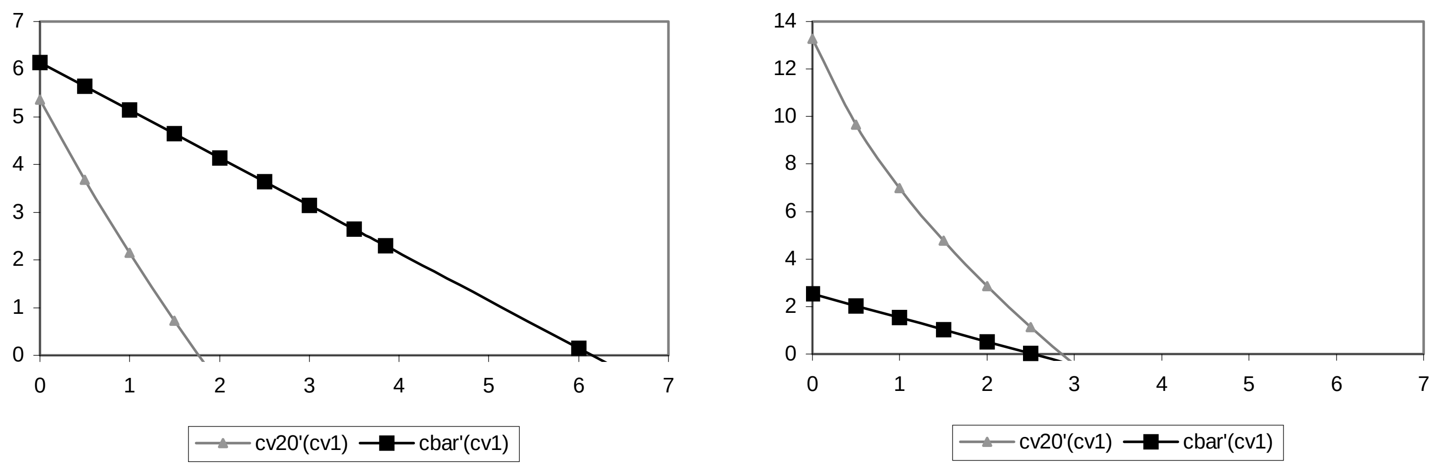
FIGURE 7
No-Surprises VCA Outcomes



b. Surprises

Next, we illustrate the case of a VCA that does not offer assurances. We start by illustrating the possibility that no VCA will be reached if the expected additional conservation and the degree of uncertainty are high enough. We set p = 0.37, ω_1 = 5, $E\omega_2$ = 4, a_m = 1.1, a_v = 1.09, A = 72, q = 0.5. When c_s^E = 35 and σ = 70, a VCA is reached (see Fig. 8a). However, when c_s^E = 38.5 and σ = 75.5, no VCA is reached (see Fig. 8b). It is easy to verify that condition (15) holds for these parameter values.

FIGURE 8



(a) VCA: c_s^E = 35, σ = 70

(b) No VCA: c_s^E = 38.5, σ = 75.5

Finally, we assume that a VCA is reached and compare the outcomes with those of a no-surprises VCA. The parameter values are the same as those used to generate Table I, and we set q = 0.8. Table II shows the conservation outcomes for various levels of p and different allocations of bargaining power. To make the comparison interesting we assume that no additional conservation takes place in period 2 (i.e. $c_s = 0$), except in Scenario 1b.

TABLE II
Surprises Conservation Outcomes

Scenario	$\overline{C}-qEc_{v2}^F$	(c_{v1}^F, c_{v2}^F)	$(c_{v1}^{R'}, c_{v2}^{R'})$	(c_{m1}^*, Ec_{m2}^*)	$(c_{v1}^{L'}, c_{v2}^{L'})$
1b: p=0.8, $BP=R$, $c_s>0$	4179	**(1791,1792)**$^+$	-------	(1791,1792)	-------
2b: p= 0.4, $BP=R$, c_s= 0	1193	(1791,1792)	**(994,995)**$^+$	(1791,1792)	-------
3b: p=0.8, $BP=L$, c_s= 0	4179	(1791,1792)	-------	(1791,1792)	**(751,752)**$^+$

The outcome in each scenario is indicated by the $^+$ *sign.*

Scenario 1b illustrates a case in which the first-best outcome is achieved. Because $c_{v1}^F+(1-q)c_{v2}^F=$ 2149 < $\overline{C}-qEc_{v2}^F$ = 4179, this outcome is acceptable to the landowner. In Scenario 2b, the probability of regulation is lower. The first-best outcome is no longer achievable, and the regulator chooses $(c_{v1}^{R'}, c_{v2}^{R'})$. Note that the total conservation outcome is lower than that attainable under regulation. It is also lower than that achieved with a no-surprises VCA (Scenario 2a in Table I). Finally, in Scenario 3b the landowner has the bargaining power. Compare this case with Scenario 4a in Table I. The probability of regulation is the same, but the outcome chosen by the regulator yields a lower total conservation in Scenario 3b, where additional conservation in period 2 is expected. It is evident from comparing the outcomes in Table I and Table II that offering assurances to landowners can increase the conservation level obtained from a VCA, particularly when the likelihood of regulation is low and the landowners has the bargaining power. This simple numerical example illustrates that all the scenarios discussed in the theoretical model are possible.

V. CONCLUSIONS

This paper analyzed the conditions that lead to VCA, and the resulting conservation levels. The analysis showed that whether a VCA is reached depends on whether assurances are offered as part of the agreement or not. In particular, offering assurances may increase the likelihood that a VCA will be reached. Specifically, the landowner and the regulator may not reach a VCA when there is a large degree of uncertainty regarding future conservation requirements. In addition, VCAs that do not offer assurances may result in lower levels of conservation than VCAs that do. Finally, the conservation level resulting from a VCA may also be lower under irreversibility than when management actions taken under the VCA are reversible.

Our analysis also showed that the conservation level generated by a VCA depends on which party has the bargaining power, as well as on the irreversibility of actions taken in the first period. Specifically, the conservation level will be lower when the landowner has the bargaining power. Furthermore, we argued that in practice the conservation levels generated by a VCA are likely to be inadequate because the landowner has an informational advantage, and because the threat of regulation is low. Under these circumstances, combining assurances with financial incentives might increase the level of conservation achieved by a VCA.

Although our analysis has focused on the specific issue of endangered species, the framework presented here should apply to other contexts in which uncertainty and irreversibility are relevant and assurances-based incentives are used to complement command-and-control regulation. For instance, industries negotiating plans for management of imperiled aquatic ecosystems have sought assurances against enforcement of the Clean Water Act, the Federal Power Act, and several other federal and state environmental laws. Similarly, the electric utility industry has lobbied Congress to include no-surprises clauses in relicensing agreements for hydroelectric facilities, so that the terms of the license could not be revised due to environmental reasons (Kostyack 1998).

APPENDIX

Proof of Proposition 1

We need to show that $c_{v1}^{Min} \leq \overline{C}$ and $c_{v2}^{Min} \leq \overline{C}$ for all $p > 0$. We prove that this holds for c_{v1}^{Min}; the argument for c_{v2}^{Min} is the same. The acceptance set for the regulator can be written as

$$S_R = \{(c_{v1},c_{v2})|\ c_{v1} + c_{v2} \leq \overline{C} + (1/a_v)[B_1(c_{v1}) + EB_2(c_{v2}) - p(B_1(c_{m1}^*) + EB_2(c_{m2}^*))]\} \qquad \text{(A1)}$$

If no conservation takes place in period 2, (A1) becomes

$$S_R = \{(c_{v1},0)|\ c_{v1} \leq \overline{C} + (1/a_v)[B_1(c_{v1}) - p(B_1(c_{m1}^*) + EB_2(c_{m2}^*))]\} \qquad \text{(A2)}$$

For small enough values of c_{v1}, (A2) does not hold. To see this, note that for small c_{v1} the left hand side of (A2) will be positive, whereas the right hand side will be negative, since $p(B_1(c_{m1}^*) + EB_2(c_{m2}^*)) > 0$. c_{v1}^{Min} is defined as the minimum conservation level for which (A2) holds with equality:

$$c_{v1}^{Min} = \overline{C} + \frac{1}{a_v}[B_1(c_{v1}^{Min}) - p(B_1(c_{m1}^*) + E\ B_2(c_{m2}^*))] \qquad \text{(A3)}$$

This implies that for any conservation level smaller than c_{v1}^{Min}, the left hand side of (A3) is positive, whereas the right hand side is negative. That is, there exists an arbitrarily small $\varepsilon > 0$ such that $c_{v1}^{Min} - \varepsilon > 0$ and $\overline{C} + (1/a_v)\ [B_1(c_{v1}^{Min} - \varepsilon) - p(B_1(c_{m1}^*) + E\ B_2(c_{m2}^*))] < 0$.

Since $\overline{C} = p(a_m/a_v)(c_{m1}^* + Ec_{m2}^*) > 0$ and $a_v > 0$, this implies $B_1(c_{v1}^{Min} - \varepsilon) - p(B_1(c_{m1}^*) + E\ B_2(c_{m2}^*)) < 0$.

Given that ε is arbitrarily small, the continuity of the benefit function implies that

$B_1(c_{v1}^{Min}) - p(B_1(c_{m1}^*) + EB_2(c_{m2}^*)) \leq 0$. Finally, from (A3), this means that $c_{v1}^{Min} \leq \overline{C}$.

Proof of Proposition 2

First, note that the first-best outcome will only be achieved if $E\omega_2 = \omega_2$, which will generally not be the case. Consider next the case where the participation constraint for the landowner is not binding, and hence the regulator offers the second-best conservation levels (c_{v1}^*, c_{v2}^*). This means that $c_{vi}^* = \arg\max NSB_{vi} > c_{mi}^* = \arg\max NSB_{mi}$, $i = 1, 2$, and therefore $c_{v1}^* + c_{v2}^* > c_{m1}^* + Ec_{m2}^*$. This, together with the participation constraint $c_{v1}^* + c_{v2}^* \leq p(a_m/a_v)(c_{m1}^* + Ec_{m2}^*)$, implies that $p(a_m/a_v) > 1$.

If the participation constraint is binding, the conservation level is $c_{v1}{}^R + c_{v2}{}^R = \overline{C} = p(a_m/a_v)(c_{m1}{}^* + Ec_{m2}{}^*)$. In this case, if $p(a_m/a_v) < 1$, then $c_{v1}{}^R + c_{v2}{}^R < c_{m1}{}^* + Ec_{m2}{}^*$.

Proof of Proposition 3

The conservation levels chosen by the landowner are

$$(c_{v1}{}^L, c_{v2}{}^L) = arg\ min\ \{a_v(c_{v1} + c_{v2}) | (c_{v1}, c_{v2}) \in S_R\}, \tag{A4}$$

and the corresponding total conservation level is $c_{v1}{}^L + c_{v2}{}^L$. The total conservation level chosen by the regulator is $c_{v1}{}^* + c_{v2}{}^*$, if $c_{v1}{}^* + c_{v2}{}^* \leq \overline{C}$, or $c_{v1}{}^R + c_{v2}{}^R$ otherwise, where $(c_{v1}{}^*, c_{v2}{}^*)$, $(c_{v1}{}^R, c_{v2}{}^R) \in S_R$. Suppose that $c_{v1}{}^L + c_{v2}{}^L > c_{v1}{}^* + c_{v2}{}^*$. This implies that $a_v(c_{v1}{}^L + c_{v2}{}^L) > a_v(c_{v1}{}^* + c_{v2}{}^*)$, which contradicts (A4). The same argument holds for $c_{v1}{}^R + c_{v2}{}^R$. Thus, it must be that $c_{v1}{}^L + c_{v2}{}^L \leq c_{v1}{}^* + c_{v2}{}^*$, and $c_{v1}{}^L + c_{v2}{}^L \leq c_{v1}{}^R + c_{v2}{}^R$.

To see that the conservation level chosen by the landowner is smaller than $c_{m1}{}^* + Ec_{m2}{}^*$ if $p(a_m/a_v) < 1$, note that the lower boundary of S_R, $(c_{v1}, c_{v2}{}^0(c_{v1}))$, is defined by

$$c_{v1} + c_{v2} = p\,(a_m/a_v)(c_{m1}{}^* + Ec_{m2}{}^*) + 1/a_v\,[B_1(c_{v1}) + EB_2(c_{v2}) - p(B_1(c_{m1}{}^*) + EB_2(Ec_{m2}{}^*))] \tag{A5}$$

Following the same logic as in the proof of proposition 1, there exist arbitrarily small $\varepsilon_1 > 0$ and $\varepsilon_2 > 0$ such that $(c_{v1} - \varepsilon_1) + (c_{v2} - \varepsilon_2) > 0$ and $B_1(c_{v1} - \varepsilon_1) + EB_2(c_{v2} - \varepsilon_2) - p(B_1(c_{m1}{}^*) + EB_2(Ec_{m2}{}^*)) < 0$. Given that ε_1 and ε_2 are arbitrarily small, the continuity of the benefit function implies that $B_1(c_{v1}) + EB_2(c_{v2}) - p(B_1(c_{m1}{}^*) + EB_2(Ec_{m2}{}^*)) \leq 0$. Therefore, $c_{v1} + c_{v2} < c_{m1}{}^* + Ec_{m2}{}^*$ for $p(a_m/a_v) < 1$.

Proof of Proposition 4

It is easy to see that if $c_{v2}'(c_{v1}) > \overline{C'} - c_{v1}$ for any $c_{v1} \in [0, \overline{C'}]$, then $\{S_R' \cap S_L'\} = \emptyset$, so no VCA is reached. To see that this may be the case if the expected surprise and the degree of uncertainty are large, let condition (14) hold with equality, and write $c_{v2}'(c_{v1})$ as

$$\begin{aligned} c_{v2}'(c_{v1}) = \overline{C} - c_{v1} + (1/a_v)[B_1(c_{v1}) + EB_2(c_{v2}'(c_{v1})) - p(B_1(c_{m1}{}^*) + EB_2(c_{m2}{}^*))] + \\ (q/a_v)[EB_2(c_{v2}'(c_{v1}) + c_s{}^E + \sigma\phi(\gamma)/q) - EB_2(c_{v2}'(c_{v1})) - a_v(c_s{}^E + \sigma\phi(\gamma)/q)]\} \end{aligned} \tag{A6}$$

Note that $\overline{C'} = \overline{C} - q(c_s{}^E + \sigma\phi(\gamma)/q)$ and rearrange (A6) to obtain

$$c_{v2}'(c_{v1}) - (\overline{C}' - c_{v1}) = (1/a_v)[B_1(c_{v1}) + EB_2(c_{v2}'(c_{v1})) - p(B_1(c_{m1}^*) + EB_2(c_{m2}^*))] +$$

$$(q/a_v)[EB_2(c_{v2}'(c_{v1}) + c_s^E + \sigma\phi(\gamma)/q) - EB_2(c_{v2}'(c_{v1}))] \quad \text{(A7)}$$

The second expression on the right side of (A7) is always positive, since $B(\bullet)$ is increasing. If the first term on the right side of (A7) is positive as well, then $c_{v2}'(c_{v1}) > (\overline{C}' - c_{v1})$. If the first term is negative, then $c_{v2}'(c_{v1}) > (\overline{C}' - c_{v1})$ will hold if the second term on the right of (A7) is large enough, i.e. if $c_s^E + \sigma\phi(\gamma)/q$ is large enough. To show that this is possible, it suffices to present an example. With the quadratic functional form, the boundary of S_R' is given by

$$c_{v2}'(c_{v1}) = A - a_v - E\omega_2 - q(c_S^E + (\sigma\phi(\gamma)/q)) - \{[A - a_v - E\omega_2 - q(c_S^E + (\sigma\phi(\gamma)/q))]^2 - E\omega_2^2 + 2[A - q(c_S^E +$$

$$(\sigma\phi(\gamma)/q))]E\omega_2 + 2q(A - a_v)(c_S^E + (\sigma\phi(\gamma)/q)) - q(c_S^E + (\sigma\phi(\gamma)/q))^2 + 2A(c_{v1}+\omega_1) - (c_{v1}+\omega_1)^2 -$$

$$2a_v c_{v1} - 2p[NSB_{m1}(c_{m1}^*)+ENSB_{m2}(Ec_{m2}^*)]\}^{1/2} \quad \text{(A8)}$$

Using (A8) and $\overline{C}' = \overline{C} - q(c_s^E + \sigma\phi(\gamma)/q)$, and defining

$D \equiv p(a_m/a_v)[2(A - a_m) - \omega_1 - E\omega_2] - \omega_1 - E\omega_2$ and

$E \equiv 2(A - a_v - E\omega_2)\, p(a_m/a_v)[2(A - a_m) - \omega_1 - E\omega_2] - [p(a_m/a_v)(2(A - a_m) - \omega_1 - E\omega_2)]^2 +$
$2A(\omega_1 + E\omega_2) - (\omega_1^2+E\omega_2^2) - 2p[(A - a_m)^2 + a_m(\omega_1 + E\omega_2)]$

it is straightforward to show that $c_{v2}(c_{v1}) - (\overline{C}' - c_{v1}) > 0$ if and only if $c_S^E + (\sigma\phi(\gamma)/q) > [(2(Dc_{v1} - c_{v1}^2)+E)/q(1-q)]^{1/2}$, which gives condition (15).

Proof of Proposition 5

Consider first the case where the participation constraint for the landowner is not binding. This means that $c_{vi}^* = arg\ max\ NSB_{vi} > c_{mi}^* = arg\ max\ NSB_{mi}$, i = 1, 2, and therefore $c_{v1}^*+c_{v2}^* > c_{m1}^*+Ec_{m2}^*$. This and $c_{v2}^* = Ec_{v2}^F$ imply that $c_{v1}^*+(1\text{-}q)c_{v2}^* > c_{m1}^*+Ec_{m2}^* - qEc_{v2}^F$. Together with the participation constraint, this implies that $p(a_m/a_v) > 1$. The regulator will choose c_{v1}^F in the first period. If $c_s > 0$, the total conservation level is $c_{v1}^F + c_{v2}^F$, which is the first-best. If $c_s = 0$, the total conservation level is $c_{v1}^F + Ec_{v2}^F = c_{v1}^* + c_{v2}^*$ (see (6)), which is the second-best. This is the best outcome that can be achieved with a no-surprises VCA.

Now consider the case where the constraint is binding. Since $\partial \overline{C} / \partial (p\, a_m/a_v) = c_{m1}^* + Ec_{m2}^* > 0$, this is the case for $p(a_m/a_v) \leq 1$. The regulator chooses conservation levels $(c_{v1}^{R'}, c_{v2}^{R'})$ such that $c_{v1}^{R'} + (1-q)c_{v2}^{R'} = \overline{C} - qEc_{v2}^F$. If $c_s > 0$, the total conservation level will be $c_{v1}^{R'} + c_{v2}^F$, which is not the first best. If $c_s = 0$, the first-best will not be achieved either.

To show that the total conservation level may be lower than that achieved in a no surprises VCA, i.e. $c_{v1}^{R'} + c_{v2}^{R'} < c_{v1}^R + c_{v2}^R = \overline{C}$, we present an example. Suppose by contradiction that $c_{v1}^{R'} + c_{v2}^{R'} \geq \overline{C}$. When benefits are quadratic, the regulator chooses $c_{v1}^{R'} = [(\overline{C} - qEc_{v2}^F - E\omega_2 + \omega_1)/(2-q)] + E\omega_2 - \omega_1$ and $c_{v2}^{R'} = (\overline{C} - qEc_{v2}^F - E\omega_2 + \omega_1)/(2-q)$, and this condition becomes

$$[2(\overline{C} - qEc_{v2}^F) - q(E\omega_2 - \omega_1)]/(2-q) \geq \overline{C}.$$

Inserting the expressions for $\overline{C}$, c_{m1}^*, Ec_{m2}^*, and Ec_{v2}^F, rearranging, and simplifying we can rewrite this as

$$2A - 2a_v - E\omega_2 - \omega_1 \leq p(a_m/a_v)(2A - 2a_m - E\omega_2 - \omega_1).$$

Given $p(a_m/a_v) \leq 1$ this implies $2A - 2a_v - E\omega_2 - \omega_1 \leq 2A - 2a_m - E\omega_2 - \omega_1$, or $a_v \geq a_m$, which contradicts our assumption of lower marginal costs under a VCA.

Finally, $c_{v1}^{R'} + c_{v2}^{R'} < \overline{C} = p(a_m/a_v)(c_{m1}^* + Ec_{m2}^*)$ and $p(a_m/a_v) \leq 1$ imply that $c_{v1}^{R'} + c_{v2}^{R'} < c_{m1}^* + Ec_{m2}^*$.

Proof of Proposition 6

To see that the outcome will not be the first best when the landowner has the bargaining power, note that the total conservation level when $c_s > 0$ is $c_{v1}^{L'} + c_{v2}^F$, which in general will not equal $c_{v1}^F + c_{v2}^F$. Additionally, the first best will not be reached if $c_s = 0$.

The total conservation level when $c_s = 0$ is $c_{v1}^{L'} + c_{v2}^{L'}$. To see that this is smaller than the total conservation achieved when the regulator has the bargaining power, suppose by contradiction that it is not. Then

$c_{v1}^{L'} + c_{v2}^{L'} \geq c_{v1}^{R'} + c_{v2}^{R'} > c_{v1}^{R'} + (1-q)c_{v2}^{R'} = \overline{C} - qEc_{v2}^{F}$, which yields a contradiction, since $\overline{C} - qEc_{v2}^{F}$ is the maximum conservation level acceptable to the landowner (see (16)). Thus, we must have $c_{v1}^{L'} + c_{v2}^{L'} < c_{v1}^{R'} + c_{v2}^{R'}$.

To show that the total conservation may be lower than in a no surprises VCA, it suffices to present an example. To see that $c_{v1}^{L'} + c_{v2}^{L'} < c_{v1}^{L} + c_{v2}^{L}$ when $p(a_m/a_v) \leq 1$, we use the quadratic functional form to solve (8) and (16) and derive the expressions for $c_{v1}^{L'} + c_{v2}^{L'}$ and $c_{v1}^{L} + c_{v2}^{L}$. The derivation is straightforward but tedious, so it is not presented here. Using these results and assuming, by contradiction, that $c_{v1}^{L} + c_{v2}^{L} \leq c_{v1}^{L'} + c_{v2}^{L'}$, we obtain

$$2(A-a_v-E\omega_2) - 2[(a_v-A+E\omega_2)^2 - a_v(E\omega_2-\omega_1-\overline{C}) + 2AE\omega_2 - E\omega_2^2 - p(B_1(c_{m1}^*)+EB_2(Ec_{m2}^*)]^{1/2} + E\omega_2 - \omega_1 \leq$$

$$2(A-a_v-E\omega_2) - 2[(a_v-A+E\omega_2)^2 - (2a_v/(2-q))(E\omega_2-\omega_1-\overline{C}) + 2AE\omega_2 - E\omega_2^2 - (2/(2-q))\, p(B_1(c_{m1}^*)+EB_2(Ec_{m2}^*)) + (2q/(2-q))ENSB_{v2}(Ec_{v2}^F)]^{1/2} + E\omega_2 - \omega_1.$$

By substituting in the expressions for c_{m1}^*, Ec_{m2}^*, $\overline{C}$, and Ec_{v2}^F, simplifying, and rearranging, we obtain

$$p(A-a_m)^2 - (A-a_v)^2 + (pa_m - a_v)(\omega_1 + E\omega_2) \geq 0. \qquad \text{(A9)}$$

Given $a_m > a_v$, it is easy to see that $p(A-a_m)^2 - (A-a_v)^2 < 0$. Additionally, $p(a_m/a_v) \leq 1$ and $\omega_1, E\omega_2 > 0$ imply that $(pa_m - a_v)(\omega_1 + E\omega_2) \leq 0$. This means that (A9) yields a contradiction. Thus, we must have $c_{v1}^{L} + c_{v2}^{L} > c_{v1}^{L'} + c_{v2}^{L'}$.

Finally, to see that when $c_s = 0$ and $p(a_m/a_v) \leq 1$ the total conservation level is lower than that expected under regulation, note that $c_{v1}^{L'}+c_{v2}^{L'} < c_{v1}^{R'}+c_{v2}^{R'}$, as shown above, and $c_{v1}^{R'}+c_{v2}^{R'} < c_{m1}^*+Ec_{m2}^*$, as shown in the proof of Proposition 5.

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